

The *Petrocephalus* (Pisces, Osteoglossomorpha, Mormyridae) of Gabon, Central Africa, with the description of a new species

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ABSTRACT

In this paper, we study variation in the morphology and electric organ discharges (EODs) of *Petrocephalus* Marcusen, 1854 (Pisces, Osteoglossomorpha, Mormyridae) collected in Gabon, Central Africa. We recognize four valid species: *P. simus* Sauvage, 1879, *P. balayi* Sauvage, 1883 (= *Mormyrus amblystoma* Günther, 1896), *P. microphthalmus* Pellegrin, 1908, and *P. sullivan* n. sp. *Petrocephalus sullivan* n. sp. differs from all others by the following combination of characters: lack of black spot at the base of the dorsal fin; more than 18 branched rays on the dorsal fin; more than 14 scales (rarely 14) between the origin of the anal fin and the lateral line; inferior mouth with the distance from the anterior extremity of the snout to the mouth between 2.7 and 4.4 times in head length (average 3.2); and EOD duration 216 ± 29 microseconds, with prominent third phase (P3). We summarize the geographical distribution of each species and provide a key to species of the genus *Petrocephalus* from Gabon based on diagnostic characteristics from external morphology.

KEY WORDS

Pisces,
Mormyridae,
electric fishes,
EOD,
Gabon,
Africa,
Petrocephalus sullivan n. sp.,
new species.

RÉSUMÉ

Les Petrocephalus (Pisces, Osteoglossomorpha, Mormyridae) du Gabon, Afrique Centrale, avec la description d'une nouvelle espèce.

Dans ce travail, nous étudions la variabilité morphologique ainsi que la forme des décharges électriques organiques (DEO) des *Petrocephalus* Marcusen, 1854 (Pisces, Osteoglossomorpha, Mormyridae) présents au Gabon (Afrique Centrale). Ceci nous a permis d'y reconnaître quatre espèces : *P. simus* Sauvage, 1879, *P. balayi* Sauvage, 1883 (= *Mormyrus amblystoma* Günther, 1896), *P. microphthalmus* Pellegrin, 1908 et *P. sullivanii* n. sp. *Petrocephalus sullivanii* n. sp. se distingue des trois autres espèces par la combinaison des caractères suivants : absence de tache noire sous-dorsale ; plus de 18 rayons branchus à la nageoire dorsale ; plus de 14 écailles (rarement 14) entre l'origine de la nageoire anale et la ligne latérale ; la bouche est située en position infère, la distance du museau à la bouche étant comprise en moyenne 3,2 fois dans la longueur de la tête (minimum : 2,7 et maximum : 4,4). Enfin, les DEO ont une durée de 216 ± 29 microsecondes, avec une troisième phase (P3) proéminente. La distribution géographique de chacune des quatre espèces est résumée et une clé d'identification des espèces de *Petrocephalus* du Gabon est proposée, qui est fondée sur des caractères diagnostiques de la morphologie externe.

MOTS CLÉS

Pisces,
Mormyridae,
poissons électriques,
DEO,
Gabon,
Afrique,
Petrocephalus sullivanii n. sp.,
nouvelle espèce.

INTRODUCTION

The subfamily Petrocephalinae Taverne, 1972 (Pisces, Osteoglossomorpha, Mormyridae) contains a single genus, *Petrocephalus* Marcusen, 1854 with 25 species (Froese & Pauly 2003). With an average size of 10 cm, *Petrocephalus* species are comparatively small mormyrids that live in schools at the bottom of rivers and rarely in lakes. *Petrocephalus* differ from other Mormyridae by having an orbitosphenoid, a basisphenoid, two nostrils closely apposed with the posterior one very close to the eye, and two single unsegmented and unbranched rays at the origin of the dorsal fin (Taverne 1969). As with all genera in this family, these fishes produce and detect weak electric organ discharges (EODs) for purposes of object localization and communication (Hopkins 1986; Kramer 1996). Electric organ discharges may also play a key role in maintaining group cohesion within schools. The characteristics of the EODs, including the number of phases to the wave, the polarity, the duration of the component phases, and the power

spectrum, are useful, and often species-specific, characters that can aid in distinguishing morphologically-similar species (Hopkins 1981; Crawford & Hopkins 1989; Kramer & Van der Bank 2000; Sullivan *et al.* 2002; Arnegard & Hopkins 2003).

The taxonomy of *Petrocephalus* in Central Africa, and especially in the Ogooué River basin of west Central Africa (Gabon), has attracted little attention and remains obscure. The original descriptions (almost all published between the end of the 19th century and the beginning of the 20th century) are based on very few specimens. Few characters have been documented which allow the collected specimens to be identified. In Gabon, four species of this genus have been described (*P. simus* Sauvage, 1879, *P. balayi* Sauvage, 1883, *P. amblystoma* (Günther, 1896) and *P. microphthalmus* Pellegrin, 1908), among which three are valid since Boulenger (1898) synonymised *P. amblystoma* with *P. balayi*. The lack of taxonomic revision as well as identification key of species makes it difficult to identify these

species. Additionally, in our recent field studies, we have collected specimens that do not belong to any described species.

Here, we examine morphological variability among specimens of *Petrocephalus* collected in Gabon (southern part of the Lower Guinean ichthyofaunal province). We have included type material of *P. simus*, *P. balayi*, and *P. microphthalmus*, as well as types of certain species described from the nearby Congo basin for comparison, as the Lower Guinean province has faunistic affinities with this basin (Roberts 1975). Non type specimens collected in Cameroon have also been included in this study to examine the general ichthyo-geographical distribution of *Petrocephalus* species present in Gabon. In the course of recent field work in Gabon, we were also able to record and compare EODs of each species.

MATERIAL AND METHODS

We examined about 250 specimens of *Petrocephalus* collected in Gabon and neighbouring regions. They are housed in the collections of the Muséum national d'Histoire naturelle, Paris (MNHN), the Musée royal de l'Afrique Centrale, Tervuren (MRAC), the Cornell University Vertebrate Collection, Ithaca (CU) and the American Museum of Natural History, New York (AMNH). Besides the type specimens collected in Gabon (*P. simus*, *P. balayi* and *P. microphthalmus*), we included type specimens of species from the Congo basin (*P. christyi* Boulenger, 1920 [Democratic Republic of Congo, Congo basin, tributary Lindi at Bosabangui, C. Christy, MRAC 7145-7151], *P. squalostoma* (Boulenger, 1915) [Democratic Republic of Congo, Congo basin, Lukinda River tributary of Moero Lake, MRAC 14.352-14.354, one specimen examined], *P. binotatus* Pellegrin, 1924 [Democratic Republic of Congo, Congo Basin at Ikengo, H. Schouteden, MRAC 15191], *P. catostoma congicus* David & Poll, 1937 [Democratic Republic of Congo, Congo basin, Mukishi River at Lumami, 4.V.1930, R. Massart,

MRAC 30807-30808, 2 specimens seen], and *P. schoutedeni* Poll, 1954 [Democratic Republic of Congo, Congo River at Yangambi, 1948, A. Hulot coll., MRAC 120046-120055]). We examined photographs and original descriptions of type specimen of *Mormyrus amblystoma* Günther, 1896 from Gabon (holotype: BMNH 1896.5.5.101 [housed in The Natural History Museum, London], type locality: Ogooué River at Talagouga [Lower Ogooué, 00°10'S-10°43'E – estimate]).

Methods for taking counts and measurements mainly follow those of Boden *et al.* (1997) and Bigorne & Paugy (1991). For each specimen, 20 measures were taken using a digital calliper with a precision of ± 0.1 mm. Abbreviations and definitions for each of these measures follow those given by Boden *et al.* (1997), except standard length (SL), which is measured as the point-to-point distance from the anterior extremity of the snout to the posterior extremity of hypural complex, and body height (H), which is the dorso-ventral distance of the body taken at level of the origin of the anal fin.

To Boden *et al.* (1997) list we added two measures: mouth position (MP) is the point-to-point distance from the anterior extremity of the snout to the corner of the mouth, and mouth width (MW) is the point-to-point distance between the right and left corners of the mouth. Seven counts were made on each specimen: number of dorsal fin branched rays (DR) and number of anal fin branched rays (AR). Unbranched rays were counted, although they were lacking in variation (always three in the dorsal fin, two unsegmented rays and one segmented ray, and two in the anal fin, one unsegmented and one segmented ray). We counted the number of pored scales along the lateral line (SLL); the number of scales around the caudal peduncle (ScP); the number of scales between the origin of the anal fin and the lateral line, excluding the pored scale itself (ScA); and, only for some specimens, the number of teeth on the lower and upper jaws (TLJ and TUJ, respectively). *Petrocephalus* has small bicuspid teeth that are difficult to count without damage to the specimen.

We recorded EODs from live specimens soon after capture by transferring individuals to a 20 × 50 cm plastic tank filled with water from the capture site. We used silver/silver-chloride electrodes connected to a low-noise, differential recording amplifier with frequency response 0.01 Hz to 50 kHz (CWE Electronics Inc. Bio-amplifier) to sense the electric organ discharges. The amplified signals were digitized using an IOTech Wavebook sampling at 100 to 250 kHz (16-bit A/D converter, IOTech Inc., Cleveland, Ohio). Waveforms were stored on a laptop computer using custom designed software. The temperature of the water was typically between 23 and 26°C and the conductivity between 25 and 70 µS/cm. Electrodes were positioned at opposite ends of the tank, and EODs were captured when the fish faced the positive electrode. We monitored the recordings using a portable oscilloscope in order to avoid amplifier overload or signal distortion, and we used high sampling rates to capture waveform details.

EOD waveforms were analyzed with custom designed software written for Matlab (Mathworks, Inc.) using a single pulse waveform from each specimen. Each EOD was normalized so that the baseline between pulses was zero, and the peak-to-peak amplitude was set to 1.0. We also centered the zero time of the EOD to be at the midpoint between the maximum and minimum excursions of the wave. We measured times and amplitudes at recognizable landmarks on each EOD. Landmarks were taken at peaks, zero crossings, and starting and ending points that deviated by more than 1.5% of peak-to-peak height using methods adapted from previous studies with other species of mormyrids (Arnegard & Hopkins 2003). These landmarks are illustrated in Figure 1. In addition, we computed a fast Fourier transform (FFT) and peak spectral frequency of each EOD. Example FFT power spectra are illustrated in Figure 2 (right). We compared landmarks or spectral data from individual EODs using analysis of variance and made post-hoc comparisons of individual species pairs using Scheffé's test provided by *Statistica* (Statsoft, Inc.).

SYSTEMATICS

Genus *Petrocephalus* Marcusen, 1854

Petrocephalus simus Sauvage, 1879
(Figs 4A; 5A; 6A)

Petrocephalus simus Sauvage, 1879: 100.

Mormyrus simus – Sauvage 1880: 51. — Günther 1896: 292.

TYPE MATERIAL. — Syntypes: Gabon, Ogooué River at the type locality Doumé (near the modern city of Lastoursville, Gabon, 00°51'S, 12°56'E [estimate]), Expedition Savorgnan de Brazza, Alfred Marche coll., 2 ♀♀ 91.2 and 93.1 mm SL (MNHN A 0892).

OTHER MATERIAL EXAMINED. — **Gabon.** Ogooué basin, tributary Ivindo at the confluence with the Nounah River, 01°11'N, 13°08'E, 26.I.1998, C. D. Hopkins, S. Lavoué and J. P. Sullivan coll., 13 specimens (MNHN 1998-0717). — Ogooué basin, tributary Ivindo at the confluence with the Nounah River, 01°11'N, 13°08'E, XI.1964, J. Géry coll., 22 specimens (MNHN 1987-905). — Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, 11.XI.1964, J. Géry coll., 10 specimens (MNHN 1987-906). — Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, XI.1964, J. Géry coll., 2 specimens (MNHN 1987-907). — Ogooué basin at Lambaréné, 00°42'S, 10°13'E, IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 2 specimens (MNHN 2002-253). — Ogooué basin at Cap Lopez, 00°40'S, 08°50'E (estimate), 1885, Bois Guillaume coll., 1 specimen (MNHN 1885-411). — Nyanga basin, Moukalaba River nearby the ferry at Mougambou, 02°47'S, 10°43'E, 2.VII.2001, S. Lavoué and V. Mamonekene coll., 7 specimens (MNHN 2002-254). — Basin of Rembo-Nkomi, Moufoubou River at Moufoubou, 01°46'S, 10°08'E, VII.2001, S. Lavoué and V. Mamonekene coll., 7 specimens (MNHN 2002-255). — Ogooué basin at Lambaréné, 00°42'S, 10°13'E, IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 4 specimens (MNHN 2002-256). — Ogooué basin, River Onoy, 01°50'S, 11°15'E, 18.VII.2001, S. Lavoué and V. Mamonekene coll., 1 specimen (MNHN 2002-257). — Ogooué River at the National Park of La Lopé, 00°06'S, 11°35'E, 20.VIII.2001, M. E. Arnegard, C. D. Hopkins, S. Lavoué and T. Uschold coll., 18 specimens (MNHN 2002-258). — Mbari River, stream at Toucan downstream the bridge, 01°47'S, 09°53'E, 24.VII.2002, S. Lavoué and O. G. Pauwels coll., 1 specimen (MNHN 2003-607). — Beneath Ogooué River bridge West of Franceville, 01°38'S,

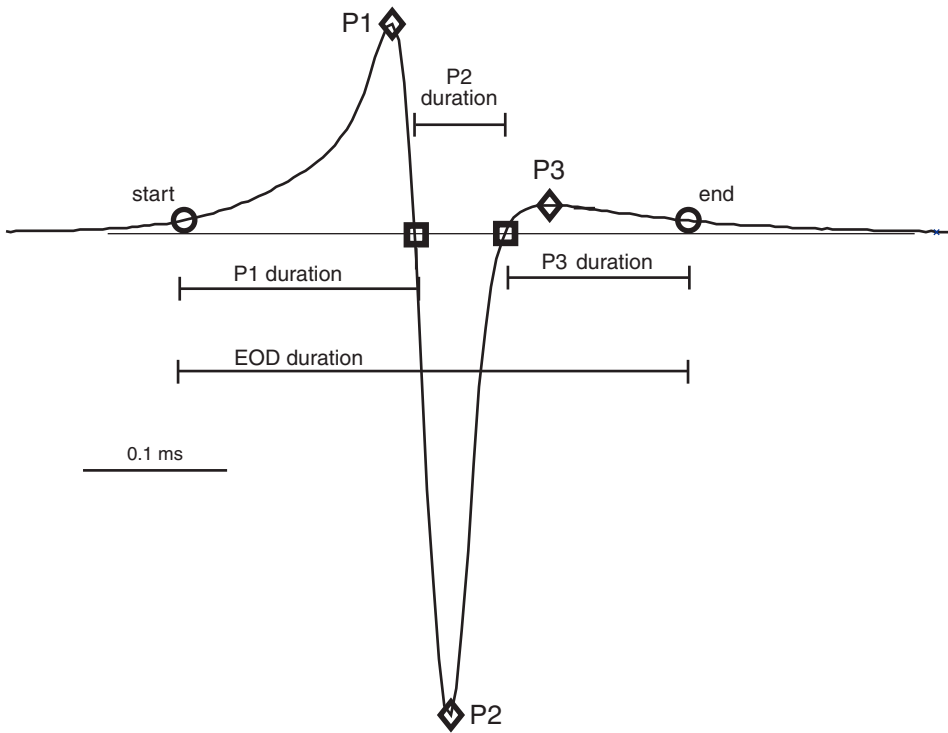


FIG. 1. — Electric organ discharge (EOD) waveform of *Petrocephalus simus* Sauvage, 1879 with landmarks indicated by symbols. Head positive is upward in this and all other EOD plots. Open circles mark the start and end of the waveform, defined as the first and last points that deviate from the baseline by at least 1.5% of the peak-to-peak height. P1, P2, and P3 mark three peaks in the waveform. Zero-crossings, indicated by open squares, are used to delimit the beginning and end of phase P2. The sampling rate in this example was 250 kHz.

13°31'E, 11.VII.1999, M. E. Arnegard, J. P. Sullivan and A. Lehman coll., 1 specimen (AMNH 233593). — Louetsi River couple 100 m downstream of Bongolo Bridge, 02°14'S, 11°27'E, 21.VII.1999, J. P. Sullivan and J. Beck coll., 1 specimen (CU80322). — Ntem River near auberge d'Ayengbe, 02°13'N, 11°44'E, 7.IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 1 specimen (CU80924). — Ogooué basin, tributary Ivindo at the confluence with the Nounah River, 01°11'N, 13°08'E, 27.I.1998, C. D. Hopkins, S. Lavoué and J. P. Sullivan coll., 4 specimens (CU). — Beneath Ogooué River bridge West of Franceville, 01°38'S, 13°31'E, 7.VIII.1999, M. E. Arnegard, J. P. Sullivan and A. Lehman coll., 1 specimen (CU80539). — Ntem River, "Deghe" creek near auberge d'Ayengbe, 02°13'N, 11°44'E, 3.IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 1 specimen (CU80699). — Ogooué River, upstream point of Lambaréné Island, 00°42'S, 10°13'E, 11.VII.1999, M. E. Arnegard and J. P. Sullivan coll., 4 specimens (CU80242). — Ogooué River, north part of Lambaréné Island in

rocks, 00°42'S, 10°13'E, 17.VII.1999, M. E. Arnegard, P. Guinsoumbi and J. P. Sullivan coll., 2 specimens (CU80254). — Ntem River just in front of auberge d'Ayengbe, 02°17'N, 11°33'E, 4.IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 4 specimens (AMNH 233595). — Ogooué River at rocky point on Lambaréné Island across from Hôpital Schweitzer, 00°41'S, 10°13'E, 19.IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 2 specimens (AMNH 233596). — Louetsi River at Bongolo dam below bridge, 02°14'S, 11°27'E, 14.IX.1998, J. P. Sullivan and J. Beck coll., 1 specimen (AMNH 233599).

Cameroon. Ntem basin, without more precision, 1906, A. Cottés coll., 4 specimens (MNHN 1907-153). — Ntem basin, River Mboua which is a tributary of Kom at Ekowong, 02°31'N, 12°11'E, 21.IV.1995, A. Kamdem Toham coll., 8 specimens (MRAC 93-108-P-37-48). — Ntem basin, near the south part of Ma'an, 02°19'N, 10°38'E, 9.XII.1994, A. Kamdem Toham coll., 2 specimens (MRAC 95-030-P-299-300).

TABLE 1. — Principal counts and measurements (in mm) for the syntypes and non type specimens of *Petrocephalus simus* Sauvage, 1879 examined in this study. Abbreviations: f, female; **Min-Max**, minimum-maximum; **St-dev**, standard deviation.

	Syntype (f + f)	Non types (n = 111)		
		Min-Max	Mean	St-dev
Standard length (SL)	91.2-93.1	55.6-105.7	78.1	
SL/body height (H)	2.8-2.9	2.5-3.4	2.9	0.2
SL/head length (HL)	4.0-4.1	3.4-4.3	3.8	0.2
SL/predorsal distance (PDD)	1.6-1.6	1.5-1.8	1.6	0.0
SL/preanal distance (PAD)	1.7-1.7	1.5-1.8	1.6	0.1
SL/dorsal fin length (DFL)	4.2-4.4	3.8-5.5	4.7	0.3
SL/anal fin length (AFL)	3.5-3.5	3.1-4.3	3.6	0.2
SL/caudal peduncle length (CPL)	5.5-5.6	4.9-7.0	5.8	0.3
SL/mouth width (MW)	18.8-20.4	13.9-23.6	19.2	1.6
HL/snout length (SNL)	5.5-5.1	4.4-7.3	5.3	0.4
HL/mouth width (MW)	4.7-5.0	4.0-6.1	5.0	0.4
HL/eye diameter (ED)	3.5-3.4	3.3-4.4	3.9	0.3
HL/interorbital width (IOW)	2.9-2.8	2.5-3.5	2.8	0.2
HL/head width (HW)	2.0-2.0	1.7-2.3	1.9	0.1
HL/mouth position (MP)	4.8-5.0	3.8-6.3	4.7	0.5
CPL/caudal peduncle depth (CPD)	3.1-3.3	2.0-3.7	2.8	0.3
Dorsal fin unbranched and branched rays (DR)	III/22-III/22	III/18-III/27	III/22	
Anal fin unbranched and branched rays (AR)	II/29-II/27	II/25-II/31	II/27.3	
Number of scales on the lateral line (SLL)	38-39	36-44	38.3	
Number of scale rows between the anterior base of the anal fin and the lateral line (SDL)	14-14	10-16	12.4	
Number of teeth in the upper jaw	10-10	8-14		
Number of teeth in the lower jaw	16-16	16-22		

DIAGNOSIS. — *Petrocephalus simus* is distinguished from all other *Petrocephalus* species from Gabon by a combination of five characters: a minimum of 19 branched rays on the dorsal fin, very rarely 18 (range: 18-27; median: 22); a minimum of 11 scales, rarely 10 (range: 10-16; median: 12.4), between the anterior base of the anal fin and the lateral line; a sub-terminal mouth in which the ratio between the head length and the mouth position is between 3.8 and 6.3 (average of 4.7); a moderately wide mouth (width between 4.1 and 6.1 times in the head length, average of 5.0); and absence of a black spot near the base of the dorsal fin on either side of the body.

DESCRIPTION

Counts and measurements are shown in Table 1. *Petrocephalus simus* is a medium sized species (maximum SL observed: 105.7 mm). Body ovoid, longer than high ($2.6 < SL/H < 3.4$) and compressed. Head length between 3.4 and 4.3 times in standard length. Snout short and round. Mouth relatively narrow ($4.1 < HL/MW < 6.1$), sub-terminal, just under the anterior half of the eye. Teeth small and bicuspid, 8 to 14 in a single row in the upper jaw, 16 to 22 in the lower

jaw. Dorsal fin originates in the posterior half of the body ($1.5 < SL/PDD < 1.8$). Pre-dorsal distance equal to, or slightly greater than, the pre-anal distance ($1.0 < PDD/PAD < 1.1$). Scales cover the body, except for the head. Lateral line visible and complete with 36 to 44 pored scales along its length. Caudal peduncle relatively thin ($2.0 < CPL/CPD < 3.7$, average 2.8), although specimens from the Nyanga River basin have thicker caudal peduncles ($2.2 < CPL/CPD < 2.5$, average 2.37). Twelve scales around the caudal peduncle. Skin on head thick, with numerous electroreceptors. Skin turns opaque with formalin fixation. Three rosettes of Knollenorgan electroreceptors are present on the head: the “Nakenrosette” behind the eye and dorsal to the opercular flap, the “Kehlrosette” anterior to the pectoral fin, and the “Augenrosette” anterior and slightly dorsal to the eye (see Harder 2000).

EOD CHARACTERISTICS

EODs from this species are illustrated in Figures 1 and 2A. The electric discharge waveform begins

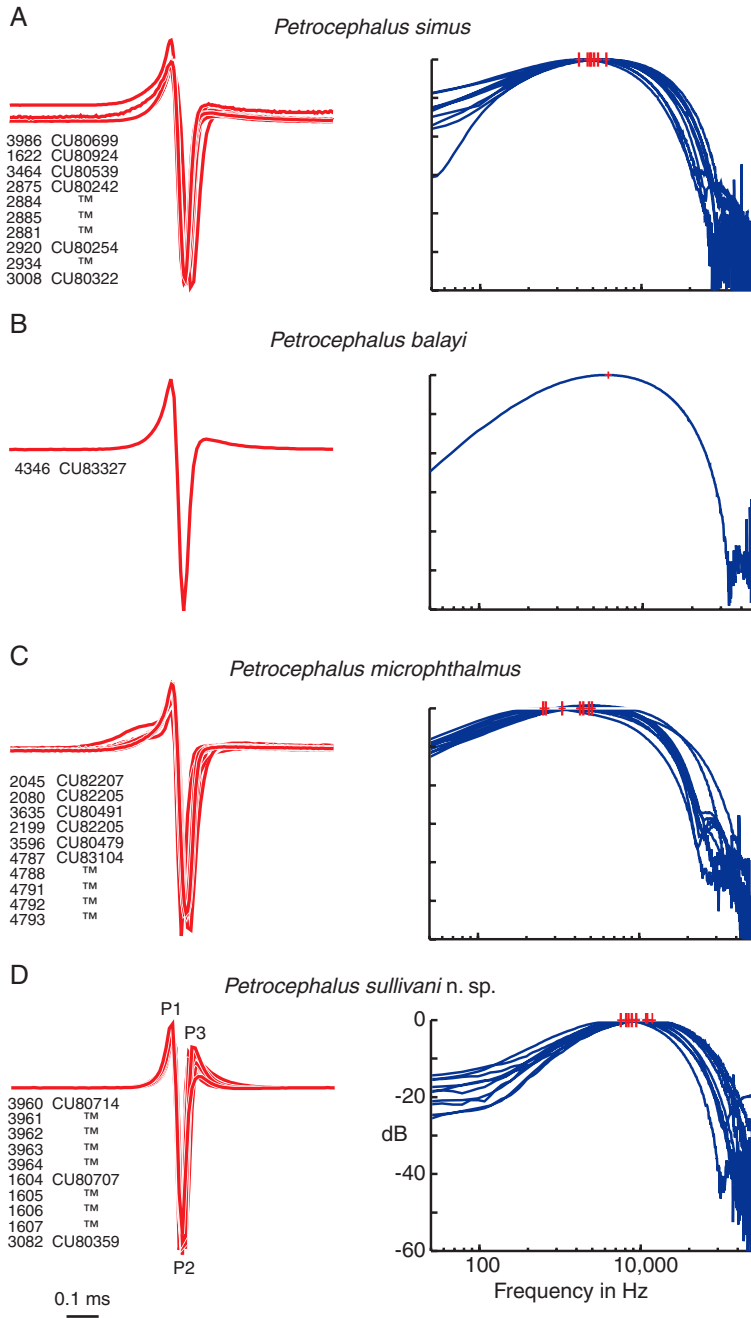


FIG. 2. — Representative electric organ discharge (EOD) waveforms (left) and power spectra of EODs (right) superimposed for 31 individuals representing four species of *Petrocephalus* from Gabon. Individual field numbers are listed to the left. All EOD recordings are made with head-positivity upward. EODs have been normalized to the same peak-to-peak height and centered around the midpoint between peaks P1 and P2.

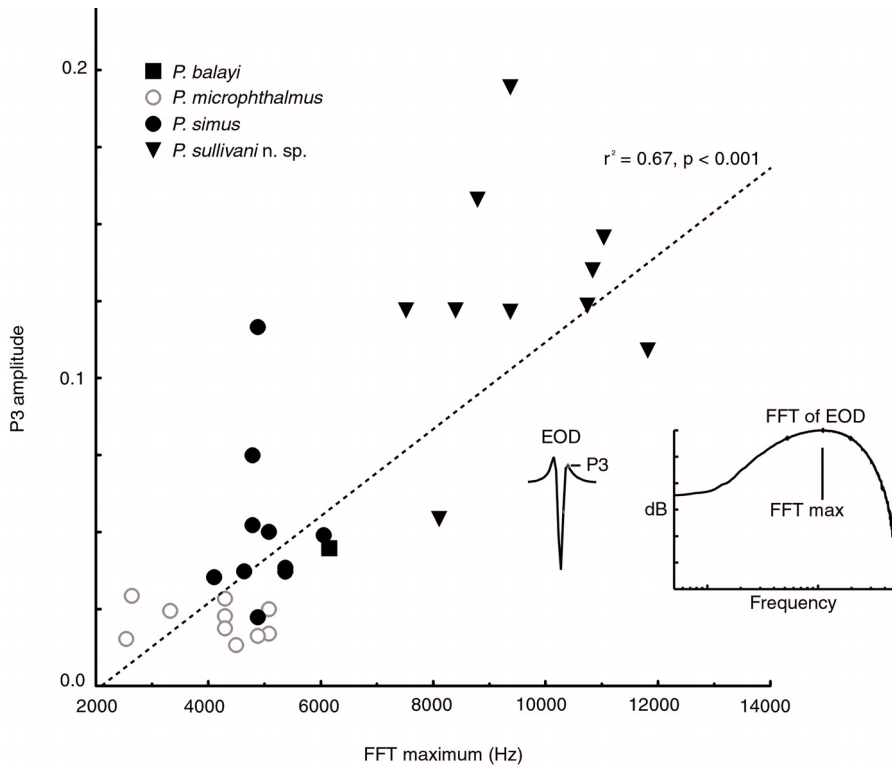


FIG. 3. — Scatterplot of the peak frequency of the Fourier Transform of an electric organ discharge (EOD) vs the relative amplitude of peak P3 for four species of *Petrocephalus* from Gabon. The inset shows examples of the two measures from a specimen of *P. sullivani* n. sp.

with a head-positive phase (P1) of approximately 26% of peak-to-peak height, followed by a larger, head-negative phase (P2) with an amplitude of 74% of peak-to-peak height, followed by a third phase (P3) with an amplitude of 5.1%. The overall duration of the pulse is $436 \pm 142 \mu\text{s}$. The FFT of the EOD peaks at 4995 Hz (Table 5).

LIVE COLORATION

Body silver, slightly darker dorsally including the head. Sub-dorsal round black spot never present on the side, as some authors have mentioned previously. Fins translucent, except for the first rays of the dorsal fin, which appear black. Moreover, the first external rays of the caudal fin are pigmented black, in a crescent shape centred on the base of the caudal fin.

DISTRIBUTION (Fig. 7)

In Gabon, *P. simus* has a widespread distribution. This species occurs in the entire Ogooué River basin, as well as the basins of the Ntem, the Rembo Nkomi and the Nyanga in the southern part of Gabon. Outside Gabon, *P. simus* was until recently considered to have a widespread distribution, stretching out to almost all hydrographical basins of West Africa and Central Africa (including the Congo basin), from Liberia to Angola. It has been commonly recorded outside Gabon (Pellegrin 1936; Poll 1939, 1967; Daget 1954, 1962; Matthes 1964), but see Discussion.

REMARKS

Populations of *P. simus* from the Ivindo and Ntem systems are morphologically closer to each

other than are populations from other parts of Gabon. In particular, individuals from Ntem and Ivindo populations possess fewer branched dorsal rays (18 to 23 [average 21.34] vs 21 to 27 [average 23] for remaining populations, largely from the Ogooué) and anal rays (25 to 28 [average 27] vs 27 to 31 [average 28]), and they have fewer scales between the anterior extremity of the anal fin and the lateral line (10 to 13 [average 11] vs 12 to 16 [average 14]).

Petrocephalus balayi Sauvage, 1883
(Figs 4B; 5B)

Mormyrus catostoma – Günther 1867: 116 (non *Mormyrus catostoma* Günther, 1866).

Petrocephalus balayi Sauvage, 1883: 159.

Mormyrus ballayi – Sauvage 1884: 195.

Petrocephalus ballayi – Pellegrin 1908: 185. — Boulenger 1909: 52. — Gosse 1984: 108.

Mormyrus amblystoma Günther, 1896: 281. — Boulenger 1909: 52.

TYPE MATERIAL. — Holotype of *P. balayi*: Gabon, Ogooué River, without more precision, Expedition Savorgnan de Brazza, Noël Ballay coll., ♀ 85.5 mm SL (MNHN A 6297).

OTHER MATERIAL EXAMINED. — **Gabon.** Ogooué basin at Ngomo (Lower Ogooué), 00°49'S, 09°57'E (estimate), E. Haug coll., 1 specimen (MNHN 1901-505); 1 specimen (MNHN 1906-159). — Coastal River Doumvou at Doumvou, 03°21'S, 10°44'E, 24.VII.2001, S. Lavoué and V. Mamonekene coll., 3 specimens (MNHN 2002-260). — Basin of Rembo-Nkomi, River Moufoubou, 01°46'S, 10°08'E, 31.VII.2001, S. Lavoué and V. Mamonekene coll., 1 specimen (MNHN 2002-261). — Coastal River Doumvou at Doumvou, 03°21'S, 10°44'E, 24.VII.2001, S. Lavoué and V. Mamonekene coll., 1 specimen (CU83327).

DIAGNOSIS. — *Petrocephalus balayi* is distinguished from all other *Petrocephalus* species from Gabon by a combination of six characters: 10 to 12 scales between the anterior base of the anal fin and the lateral line; wide mouth in comparison with the other species in this area that possess a narrower mouth (width between 2.7 and 3.9 times in the head length [average 3.3]); very distinct sub-dorsal black spot on each side of the body; more than 27 small bicuspid teeth in only one series in the lower jaw; 20 to 22 branched rays in the dorsal fin and 26 to 27 in the anal fin.

DESCRIPTION

Counts and measurements are shown in the Table 2. *Petrocephalus balayi* is the largest species of this genus in Gabon (maximum size 126 mm SL). Body ovoid, longer than deep, and compressed. Height of body between 2.5 and 3.0 times in standard length, which gives this species a heavy aspect since the caudal peduncle is short. Head length is between 3.3 and 3.6 times in standard length. Head width between 1.6 and 2.2 times in head length. Snout short, wide and square-shaped. Mouth wide (ratio between head length and mouth width ranges from 2.7 to 3.9). Mouth sub-terminal, slightly ventral. Teeth small, bicuspid, with 28 to 38 in the lower jaw and 14 to 18 in the upper jaw. Eye relatively small. Eye diameter between 4.5 and 4.9 times in head length. Dorsal fin originates in the posterior half of the body ($1.5 < SL/PDD < 1.6$). Pre-dorsal distance equal to, or slightly greater than pre-anal distance ($1.0 < PDD/PAD < 1.1$). Scales cover the entire body, except for the head. Lateral line visible and complete, with 35 to 38 pored scales. Caudal peduncle relatively thick (CPL/CPD between 1.9 and 2.3), with 12 circumpeduncular scales. Skin on head thick, with numerous electroreceptors. Skin turns opaque with formalin fixation. Three rosettes of Knollenorgan electroreceptors present on head: the “Nakenrosette”, the “Kehl-rosette” and the “Augenrosette”.

EOD CHARACTERISTICS

We recorded an EOD from just one female specimen (Fig. 2B). With a duration of 340 µs, it is shorter than those of either *P. simus* or *P. microphthalmus*, although the data are insufficient for statistical analysis (Table 5). The third peak (P3) is only 4.5% of the peak-to-peak height for this specimen.

LIVE COLORATION

Body silver, slightly darker dorsally. The head is also slightly darker than the rest of the body. Iridescent reflections sometimes appear on the side depending on the orientation of light. Presence of a distinct sub-dorsal, black, round spot on each side of the body is characteristic for this species in

TABLE 2. — Principal counts and measurements (in mm) for the holotype and non type specimens of *Petrocephalus balayi* Sauvage, 1883 examined in this study. Abbreviations: f, female; **Min-Max**, minimum-maximum; **St-dev**, standard deviation.

	Holotype (f)	Non types (n = 7)		
		Min-Max	Mean	St-dev
Standard length (SL)	85.5	126-82.2		
SL/body height (H)	2.8	2.5-3.0	2.8	0.1
SL/head length (HL)	3.3	3.3-3.6	3.5	0.1
SL/predorsal distance (PDD)	1.5	1.5-1.6	1.5	0.0
SL/preanal distance (PAD)	1.6	1.5-1.7	1.6	0.0
SL/dorsal fin length (DFL)	4.5	4.3-5.1	4.8	0.2
SL/anal fin length (AFL)	3.8	3.4-4.0	3.8	0.3
SL/caudal peduncle length (CPL)	5.7	5.1-6.6	6.0	0.4
SL/mouth width (MW)	11.2	9.3-13.7	11.1	1.3
HL/snout length (SNL)	8.1	5.4-7.6	6.2	0.9
HL/ mouth width (MW)	3.4	2.7-3.9	3.3	0.4
HL/eye diameter (ED)	4.6	4.5-4.9	4.7	0.1
HL/interorbital width (IOW)	3.2	2.6-3.1	2.8	0.2
HL/head width (HW)	2.2	1.6-2.0	1.9	0.1
HL/mouth position (MP)	5.9	5.0-5.7	5.5	0.3
CPL/caudal peduncle depth (CPD)	2.3	1.9-2.2	2.0	0.1
Dorsal fin unbranched and branched rays (DR)	III/21	III/20-III/22	III/21.7	
Anal fin unbranched and branched rays (AR)	II/26	II/26-II/27	II/26.5	
Number of scales on the lateral line (SLL)	38	35-37	35.8	
Number of scale rows between the anterior base of the anal fin and the lateral line (SDL)	11	10-12	11.0	
Number of teeth in the upper jaw	16	14-18		
Number of teeth in the lower jaw	38	28-37		

Gabon. In addition, a black and ovoid mark is present at the base of the caudal peduncle. We did not observe any special coloration on the fins, which are translucent grey in color.

DISTRIBUTION (Fig. 7)

In Gabon, *P. balayi* occurs in the lower course of the Ogooué River and numerous associated lakes (Mbega pers. comm.), as well as in small coastal rivers south of the Ogooué to the border with Congo. Elsewhere, this species has been collected from the Congo basin (David & Poll 1937; Poll 1939).

REMARKS

Lacking the holotype of *Mormyrus amblystoma* Günther, 1896, we inspected the photograph provided by Harder (2000) and the drawing in the *Catalogue of the Freshwater Fishes of Africa in the British Museum* (Boulenger 1909). Based on these and the original description (Günther 1896), we agree with Boulenger's (1898) synonymy with *P. balayi*. As in *P. balayi*, *M. amblystoma* has

a sub-dorsal black spot, a wide mouth, a short snout and only 24 rays in the dorsal fin (including two or three unbranched rays). This combination of characters is diagnostic for *P. balayi*.

P. balayi is morphologically similar to *P. sauvagii* Boulenger, 1887, which is known to occur in some coastal rivers of Cameroon, the lower course of the Niger basin and the central Congo basin. Both species live in sympatry in the Congo basin (pers. obs.). They can be easily distinguished one from the other by the number of the branched rays in the dorsal fin (26 to 28 for *P. sauvagii* vs 20 to 22 for *P. balayi*) and in the anal fin (34 to 36 for *P. sauvagii* vs 26 to 27 for *P. balayi*).

Petrocephalus microphthalmus Pellegrin, 1908 (Figs 4C; 5C; 6C)

Petrocephalus microphthalmus Pellegrin, 1908: 185.

TYPE MATERIAL. — Holotype: Gabon, Ogooué basin at Ngomo (Lower Ogooué), 00°49'S, 09°57'E

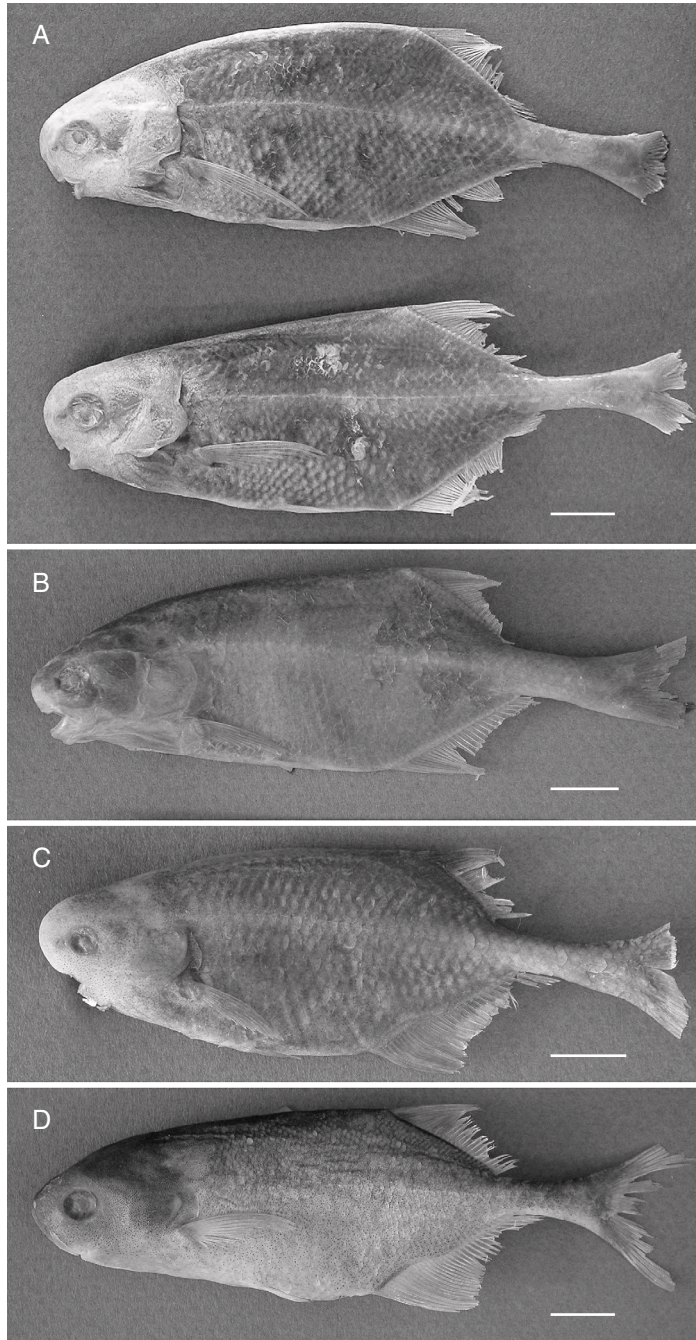


FIG. 4. — Photos of type specimens of *Petrocephalus* described from Gabon; **A**, *P. simus* Sauvage, 1879 (syntypes, MNHN A 0892, 91.1 and 93.1 mm SL); **B**, *P. balayi* Sauvage, 1883 (holotype, MNHN A 6297, 85.5 mm SL); **C**, *P. microphthalmus* Pellegrin, 1908 (holotype, MNHN 08-211, 73.7 mm SL); **D**, *P. sullivanii* n. sp. (holotype, MNHN 2003-619, 93.1 mm SL). Photographs by Rémy Ksas. Scale bars: 1 cm.

(estimate), E. Haug coll., ♂ 73.7 mm SL (MNHN 1908-211).

OTHER MATERIAL EXAMINED. — **Gabon.** Ogooué basin at Ngomo (Lower Ogooué), 00°49'S, 09°57'E (estimate), E. Haug coll., 1 specimen (MNHN 1906-160); 1 specimen (MNHN 1906-161). — Gabon, Ogooué basin from the tributary Ivindo at the confluence with the Nounah River, 01°11'N, 13°08'E, 11.VIII.1964, J. Géry coll., 7 specimens (MNHN 1987-900). — Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, IX.1964, J. Géry coll., 1 specimen (MNHN 1987-903). — Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, X.1964, J. Géry coll., 2 specimens (MNHN 1987-904). — Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, 29.I.1998, C. D. Hopkins and S. Lavoué coll., 3 specimens (MNHN 1998-722). — Gabon, Ogooué basin at Lambaréné, 00°42'S, 10°13'E, 20.X.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 3 specimens (MNHN 2002-259). — Rembo-Nkomi basin, Moufoubou River at Moufoubou, 01°46'S, 10°08'E, VII.2001, S. Lavoué and V. Mamonekene coll., 1 specimen (MNHN 2002-262). — Gabon, stream at Toucan downstream the bridge, 01°47'S, 09°53'E, 24.VII.2002, S. Lavoué and O. G. Pauwels coll., 6 specimens (MNHN 2003-608). — Ogooué River at rocky point on Lambaréné Island facing Schweitzer Hospital, 00°42'S, 10°13'E, 20.IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 10 specimens (MNHN 2003-700). — Ivindo River, mouth near Balé creek, 00°34'N, 12°52'E, 14.I.1998, C. D. Hopkins, S. Lavoué and J. P. Sullivan coll., 1 specimen (CU82207). — Ivindo River, boat landing, IRET Station, 00°34'N, 12°52'E, 15.I.1998, C. D. Hopkins, S. Lavoué and J. P. Sullivan coll., 1 specimen (CU82205). — Ogooué River, Okoloville, route from Franceville to Oroudjia, 01°29'S, 13°31'E, 12.VIII.1999, M. E. Arnégard, C. D. Hopkins, J. P. Sullivan, A. Ngankale, M. Nganjobi and J. F. Liwouwou coll., 1 specimen (CU80491). — Ivindo River near Loa Loa, 00°34'N, 12°52'E, 19.I.1998, C. D. Hopkins, S. Lavoué, J. H. Mve Beh, M. J. Stiassny and E. Vreven coll., 1 specimen (CU82205). — Ogooué River, creek crossing road near Okoloville, 01°29'S, 13°31'E, 11.VIII.1999, M. E. Arnégard, C. D. Hopkins, J. P. Sullivan, A. Ngankale, M. Nganjobi and J. F. Liwouwou coll., 1 specimen (CU80479). — Ivindo River just below Loa-Loa rapids, 00°01'N, 12°49'E, 23.VIII.2001, C. D. Hopkins and M. E. Arnégard coll., 5 specimens (CU83104). — Ogooué River at rocky point on Lambaréné Island across from Hopital Schweitzer, 00°41'S, 010°13'E, 19.IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 15 specimens (AMNH 233603). — Ivindo River just below Loa-Loa rapids, 00°31'N, 12°49'E, 23.VIII.2001, C. D. Hopkins and

M. E. Arnégard coll., 11 specimens (AMNH 233604). — Balé Creek under bridge, 00°31'N, 12°47'E, 16.I.1998, S. Lavoué and J. H. Mve Beh coll., 1 specimen (AMNH 233605); 1 specimen (AMNH 233606).

Congo. Ogooué basin from the Karagoua River, tributary of Ivindo, at Garabinzam, 01°38'N, 13°30'E, IX.1964, J. Géry coll., 1 specimen (MNHN 1987-902).

DIAGNOSIS. — *Petrocephalus microphthalmus* is distinguished from all other *Petrocephalus* species from Gabon by: few branched rays in the dorsal and anal fins (15 to 18 [average 16.5] and 23 to 27 [average 25.4], respectively); no more than 10 scales between the anterior base of the anal fin and the lateral line (range: 8-10, average 9); a small eye (diameter between 4.1 and 4.8 times in head length [average 4.5]).

DESCRIPTION

Counts and measurements are summarized in Table 3. With a maximum standard length of 73.7 mm, *P. microphthalmus* is the smallest known species of *Petrocephalus* from Gabon. Body ovoid, longer than deep (SL/H between 2.7 and 3.2, average 3.0), and compressed. Snout short and rounded. Mouth narrow ($3.5 < HL/MW < 4.9$, average 4.2), situated just below the eye. Teeth small and bicuspid, with 10 in the upper jaw and 20 in the lower jaw. Dorsal fin occupies a posterior position on the body ($1.5 < SL/PDD < 1.7$). Pre-dorsal distance equal to, or slightly greater than, pre-anal distance ($1.0 < PDD/PAD < 1.1$). Scales cover the entire body, except for the head. Lateral line visible and complete, with 33 to 36 pored scales. Eight to 10 scales between the anterior base of the anal fin and the lateral line. Twelve scales around the caudal peduncle. Skin on head thick, with numerous electroreceptors. Skin turns opaque with formalin fixation. Knollenorgan electroreceptors appear as isolated receptor pores, but do not form "rosettes" in their typical positions on the head.

EOD CHARACTERISTICS

The EOD is 487 ± 142 μ s in duration, with a peak FFT frequency at 4092 ± 942 Hz (Fig. 2C; Table 5). Peaks P1 and P2 are the same amplitude as in the other three species, but the third peak is reduced in amplitude (2.1% of peak-to-peak height).

TABLE 3. — Principal counts and measurements (in mm) for the holotype and non type specimens of *Petrocephalus microphthalmus* Pellegrin, 1908 examined in this study. Abbreviations: **m**, male; **Min-Max**, minimum-maximum; **St-dev**, standard deviation.

	Holotype (m)	Non types (n = 36)		
		Min-Max	Mean	St-dev
Standard length (SL)	73.7	52.1-69.9		
SL/body height (H)	2.7	2.7-3.2	3.0	0.2
SL/head length (HL)	4.0	3.6-4.3	3.9	0.2
SL/predorsal distance (PDD)	1.5	1.5-1.7	1.6	0.1
SL/preanal distance (PAD)	1.7	1.6-1.9	1.8	0.1
SL/anal fin length (AFL)	5.4	4.9-6.5	5.5	0.4
SL/dorsal fin length (DFL)	3.3	3.2-3.9	3.5	0.2
SL/caudal peduncle length (CPL)	5.5	4.4-5.7	5.1	0.3
SL/mouth width (MW)	15.4	13.7-19.2	16.3	0.8
HL/snout length (SNL)	4.6	4.1-6.2	4.7	0.4
HL/mouth width (MW)	3.8	3.5-4.9	4.2	0.4
HL/eye diameter (ED)	4.8	4.1-4.8	4.5	0.2
HL/interorbital width (IOW)	2.6	2.0-2.8	2.5	0.2
HL/head width (HW)	1.7	1.7-2.0	1.8	0.1
HL/mouth position (MP)	3.4	2.8-3.7	3.2	0.2
CPL/caudal peduncle depth (CPD)	2.9	2.6-3.7	3.0	0.4
Dorsal fin unbranched and branched rays (DR)	III/16	III/15-III/18	III/16.5	
Anal fin unbranched and branched rays (AR)	II/25	II/23-II/27	II/25.4	
Number of scales on the lateral line (SLL)	36	33-36	35	
Number of scale rows between the anterior base of the anal fin and the lateral line (SDL)	10	8-10	9	
Number of teeth in the upper jaw	10	9-11		
Number of teeth in the lower jaw	20	14-20		

LIVE COLORATION

Body generally blue-grey, with the dorsum darker than the abdomen. The fish can appear metallic blue to violet depending on the angle of illumination. The color is especially intense on the operculum. Numerous chromatophores occur below the skin surface. Fins translucent except for the first dorsal fin rays, which are black.

DISTRIBUTION (Fig. 7)

In Gabon, this species is present throughout the Ogooué and Ntem basins, as well as in a small coastal river (Rembo Nkomi), which is situated just south of the mouth of the Ogooué and merges with the Ogooué in coastal lagoons. Elsewhere, Daget & Depierre (1980) identified some specimens from the Sanaga River (Cameroon) as *P. microphthalmus*, but we were unable to examine them. Similarly, Poll (1967) identified some specimens from the Congo basin as *P. microphthalmus*, but these specimens were also not examined.

REMARKS

Bigorne & Paugy (1991) described *P. microphthalmus* as possessing a sub-dorsal black spot, but we did not observe this color pattern on any of the specimens we studied, including the holotype.

Petrocephalus sullivanii n. sp.
(Figs 4D; 5D; 6B)

TYPE MATERIAL. — Holotype: Gabon, Ogooué River near the park of La Lopé, 00°06'S, 11°35'N, 20.VIII.2001, M. E. Arnégard, C. D. Hopkins, S. Lavoué and T. Uschold coll., ♂ 93.1 mm SL (MNHN 2003-619). Paratypes: same locality, collectors, and date as the holotype, 32 specimens in total (MNHN 2002-266, 10 specimens; CU88992, 6 specimens and CU83120, 2 specimens; MRAC A3-06-P-1-7, 7 specimens; AMNH 233602, 7 specimens).

OTHER MATERIAL EXAMINED. — **Gabon.** Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, 1964, J. Géry coll., 2 specimens (MNHN 1987-899). — Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, 28.IX.1964,

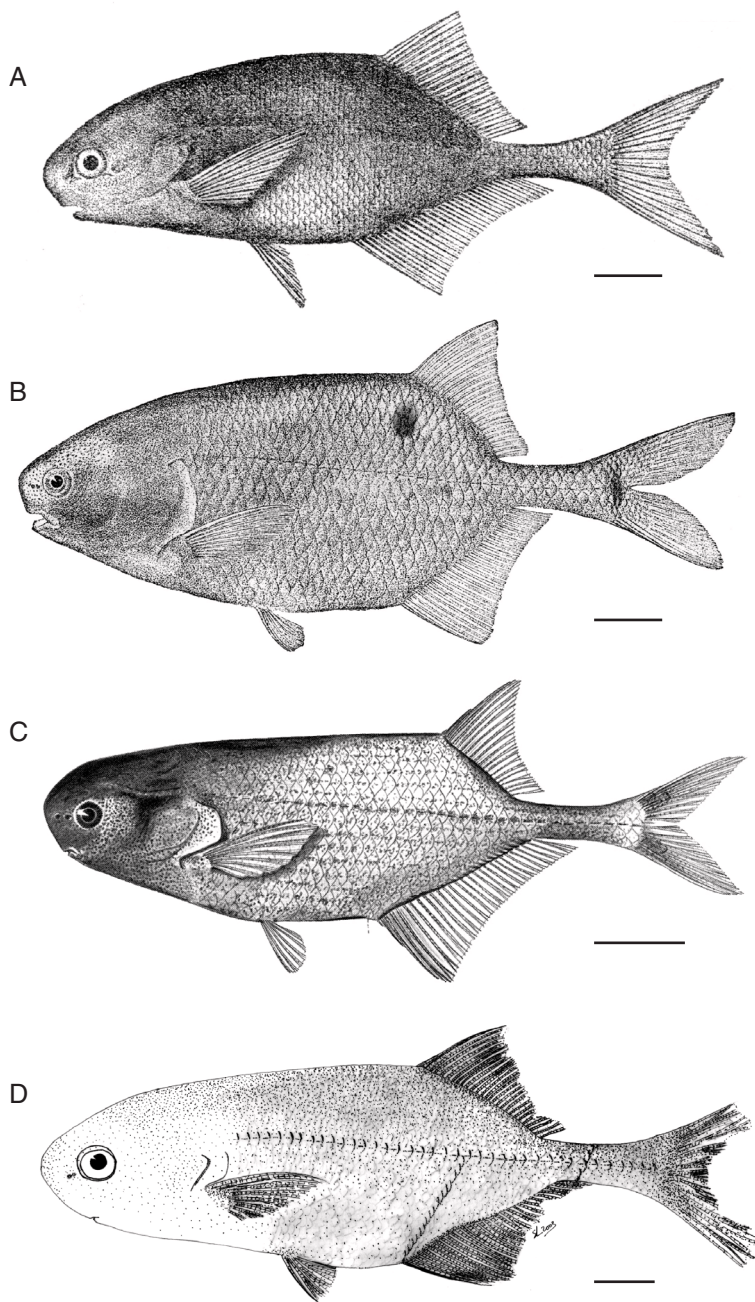


FIG. 5. — Drawing of specimens of *Petrocephalus*; **A**, *P. simus* Sauvage, 1879 (syntype, MNHN A 0892) (from Boulenger 1909-1916); **B**, *P. balayi* Sauvage, 1883 (holotype of *Mormyrus amblystoma* Günther, 1896, BMNH 1896.5.5) (from Boulenger 1909-1916); **C**, non type specimen of *P. microphthalmus* Pellegrin, 1908 from Angola (from Poll 1967); **D**, *P. sullivanii* n. sp. (holotype, MNHN 2003-619, 93.1 mm SL). Scale bars: 1 cm.

J. Géry coll., 1 specimen (MNHN 1987-898). — Nyanga basin, River Moukalaba nearby of the ferry at Mougambou, 02°47'S, 10°44'E, 22.VII.2001, S. Lavoué and V. Mamonekene coll., 4 specimens (MNHN 2002-263). — Ogooué basin River Ikoy at Ikobey, 01°03'S, 10°59'E, 30.VI.2001, S. Lavoué, V. Mamonekene and J. H. Mvé Beh coll., 1 specimen (MNHN 2002-264). — Ogooué basin, River Onoy, 01°50'S, 11°15'E, 18.VII.2001, S. Lavoué and V. Mamonekene coll., 2 specimens (MNHN 2002-265). — Ogooué basin, Louétsi River, at the falls of Bongolo, 37 km northeast of Ndendé, 02°31'S, 11°20'E, 3.X.1986, T. Roberts coll., 4 specimens (MRAC 91-79-P-89-92). — Ogooué basin, tributary Ivindo at the rapids of Loa Loa, downstream of Makokou, 00°34'N, 12°52'E, 28.IX.1964, J. Géry coll., 1 specimen (MRAC 80-15-P-59). — Ogooué basin, tributary Ivindo, Balé creek, upstream of the bridge, 00°31'N, 12°48'E, 13.IX.2001, S. Lavoué coll., 1 specimen (CU88993). — Nyanga basin, River Moukalaba, in the vicinity of the ferry at Mougambou, 02°47'S, 10°43'E, VIII.2001, S. Lavoué and D. Paugy coll., 1 specimen (CU88994). — Ogooué basin, tributary Ivindo at the confluence with the Nounah River, 01°11'N, 13°08'E, 27.I.1998, C. D. Hopkins, S. Lavoué and J. P. Sullivan coll., 3 specimens (CU). — Okoloville Creek crossing road, 01°29'S, 13°31'E, 11.VIII.1999, C. D. Hopkins, J. P. Sullivan, M. E. Arnégard, A. Ngankale, M. Nganjobi and J.-F. Liwouwou coll., 2 specimens (CU80359). — Ntem River just in front of auberge d'Ayengbe, 02°18'N, 11°33'E, 3.IX.1999, J. P. Friel, S. Lavoué and J. P. Sullivan coll., 2 specimens (CU81093); 2 specimens (CU80714); 5 specimens of which 2 examined in this study (AMNH 233600); 2 specimens (AMNH 233594). — Louétsi River, below dam in rocks, 02°14'S, 11°27'E, 23.VII.1999, J. P. Sullivan and J. Beck coll., 1 specimen (AMNH 233592). — Louétsi River just below Bongolo Dam, 02°14'S, 11°27'E, 7.IX.1998, J. P. Sullivan and J. Beck coll., 1 specimen (AMNH 233597). — Louétsi River just below Bongolo dam, 02°14'S, 11°27'E, 10.IX.1998, J. P. Sullivan and J. Beck coll., 1 specimen (AMNH 233598). — Louétsi River at Bongolo dam below bridge, 02°14'S, 11°27'E, 14.IX.1998, J. P. Sullivan and J. Beck coll., 1 specimen (AMNH 233601).

Cameroon. Ntem basin at Nyabessan, 02°24'N, 10°24'E, 1979, D. Depierre coll., 3 specimens (MNHN 1979-575). — Ntem basin at Nyabessan, 02°24'N, 10°24'E, 1979, D. Depierre coll., 1 specimen (MNHN 1979-635).

ETYMOLOGY. — We dedicate this species to our colleague and friend, John P. Sullivan, in recognition of his contributions to the systematics of the Mormyridae.

DIAGNOSIS. — *Petrocephalus sullivanii* n. sp. is distinguished from all other *Petrocephalus* species from Gabon by the following characters: 20 to 25 branched

rays in the dorsal fin and 24 to 30 in the anal fin; 14 to 20 scales (average 17.5) between the anterior base of the anal fin and the lateral line; mouth clearly inferior (distance between anterior extremity of the snout and corner of the mouth between 2.7 and 4.4 times in head length; mouth opens under the posterior half of the eye, whereas in *P. simus* and *P. balayi* it opens under the anterior half of the eye); large eye (diameter of the eye between 3.0 and 4.1 times in head length, average 3.6); and no sub-dorsal black spot. The EOD is short (216 ms mean duration) with a peak FFT frequency of 9597 Hz. The EOD presents a prominent third phase (P3) with an amplitude of 12.8% of peak-to-peak height.

DESCRIPTION

Counts and measurements are shown in Table 4. This is a species of *Petrocephalus* of medium size (maximal standard length observed = 104.7 mm). Body ovoid, longer than high ($2.8 < SL/H < 3.7$), and compressed. Snout short and very round. Mouth inferior, below the eye. Teeth small and bicuspid, with 10 to 13 in the upper jaw and 12 to 15 in the lower jaw. Eye relatively large. Eye diameter between 3.0 and 4.1 times in head length (average 3.5). Dorsal fin originates in the posterior half of the body ($1.5 < SL/PDD < 1.7$). Pre-dorsal distance equal to, or slightly greater than, pre-anal distance ($1.0 < PDD/PAD < 1.1$). Scales cover the entire body, except for the head. Lateral line visible and complete, with 35 to 42 pored scales along its length. Ratio of caudal peduncle length to height between 2.1 and 3.2 (average 2.5). Specimens from the Ivindo basin possess a somewhat thinner caudal peduncle (average 2.9), and specimens from the Nyanga River basin have somewhat thicker caudal peduncles (average 2.2), as noted for *P. simus* above. Twelve circumpeduncular scales present. Thick skin, with numerous electroreceptors, covers the head and part of the body. Skin turns opaque with formalin fixation. Three rosettes of Knollenorgan electroreceptors present on the head: the "Nakenrosette", the "Kehlrosette", and the "Augenrosette".

EOD CHARACTERISTICS

Among the *Petrocephalus* species reported here, the EODs of *P. sullivanii* n. sp. are the shortest in duration (Fig. 2D; Table 5) with the highest peak

TABLE 4. — Principal counts and measurements (in mm) for the holotype, paratypes and non type specimens of *Petrocephalus sullivanii* n. sp. examined in this study. Abbreviations: **m**, male; **Min-Max**, minimum-maximum; **St-dev**, standard deviation.

	Holotype (m)	Paratypes (n = 32)			Non types (n = 36)		
		Min-Max	Mean	St-dev	Min-Max	Mean	St-dev
Standard length (SL)	93.1	61.5-103.8	92.2		55.7-104.7	84.8	
SL/body height (H)	3.0	3.0-3.7	3.2	0.2	2.7-3.7	3.1	0.2
SL/head length (HL)	3.6	3.5-4.0	3.8	0.1	3.1-4.0	3.6	0.2
SL/predorsal distance (PDD)	1.6	1.5-1.6	1.6	0.0	1.5-1.6	1.6	0.0
SL/preanal distance (PAD)	1.7	1.6-1.7	1.6	0.0	1.5-1.7	1.6	0.0
SL/dorsal fin length (DFL)	4.4	4.1-5.0	4.5	0.2	4.0-5.0	4.5	0.2
SL/anal fin length (AFL)	3.5	3.3-3.8	3.6	0.1	3.3-3.9	3.6	0.1
SL/caudal peduncle length (CPL)	6.0	5.8-6.9	6.3	0.3	5.0-6.9	6.1	0.4
SL/mouth width (MW)	17.6	16.3-22.7	18.6	1.6	13.2-22.7	17.3	2.0
HL/snout length (SNL)	4.5	4.2-5.6	4.9	0.3	4.2-7.3	5.2	0.3
HL/mouth width (MW)	4.9	4.4-6.0	5.0	0.4	3.6-6.0	4.8	0.5
HL/eye diameter (ED)	3.8	3.2-4.1	3.6	0.2	3.0-4.1	3.5	0.2
HL/interorbital width (IOW)	3.3	2.7-3.6	2.9	0.2	2.4-3.6	2.9	0.2
HL/head width (HW)	2.1	1.9-2.3	2.0	0.1	1.7-2.3	2.0	0.1
HL/mouth position (MP)	2.8	2.7-3.9	3.2	0.3	2.7-4.4	3.2	0.3
CPL/caudal peduncle depth (CPD)	2.8	2.1-2.8	2.4	0.2	2.1-3.2	2.5	0.3
Dorsal fin unbranched and branched rays (DR)	III/25	III/21-III/25	III/23.3		III/20-III/25		
Anal fin unbranched and branched rays (AR)	II/30	II/27-II/30	II/28.4		II/24-II/30		
Number of scales on the lateral line (SLL)	38	37-42	39.3		35-42		
Number of scale rows between the anterior base of the anal fin and the lateral line (SDL)	17	16-20	17.5		14-20		
Number of teeth in the upper jaw	12	9-12			9-12		
Number of teeth in the lower jaw	18	16-22			15-22		

power spectrum frequency (Fig. 3). The third phase (P3) is also quite prominent in this species ($12.8 \pm 3.6\%$ of peak-to-peak height).

LIFE COLORATION

The body is silver to slightly gold. The back is darker than the abdomen. With differing angles of illumination, the golden metallic reflections are more prominent. The fins are unpigmented, with the exception of the first rays of the dorsal fin, which are black.

DISTRIBUTION (Fig. 7)

Petrocephalus sullivanii n. sp. has a widespread distribution in Gabon. It has been collected from the Ogooué basin (excepting its most upper and lower reaches), the Ntem and Ivindo basins, and the Nyanga basin. On numerous occasions, we collected this species together with *P. simus*.

REMARKS

Petrocephalus sullivanii n. sp. most closely resembles *P. christyi* Boulenger, 1920, described from the Congo basin. The two species are distinguished one from the other by the larger number of scales between the origin of the anal fin and the lateral line in *P. sullivanii* n. sp. (14-20, average 17.5) than in *P. christyi* (12-14, average 13); and *P. christyi* has a very distinct sub-dorsal black spot on each side of the body, which is lacking in *P. sullivanii* n. sp.

DISCUSSION

NOTE ON *PETROCEPHALUS SIMUS*

In a detailed morphometric study, Bigorne & Paugy (1991) showed that all specimens collected in West Africa (from Liberia to Nigeria), and

TABLE 5. — Time, frequency, and amplitude measures of EODs from four species of *Petrocephalus* from Gabon (means \pm standard deviations). F-statistics and p values result from analysis of variance for each variable measured. Scheffé's post-hoc test was used to test the significance of differences in means between individual species pairs. Shading indicates species pairs that are not significantly different from each other. Abbreviations: **EOD**, electric organ discharge; **FFT**, fast Fourier transform; **N.S.**, non significant; **F**, ANOVA F statistic; **p**, significance level; **, $p < 0.001$; *, $p < 0.05$; **N.S.**, $p > 0.05$; in grey, no significant difference (Scheffé's test) $p > 0.05$.

n =	<i>P. simus</i> 10	<i>P. balayi</i> 1	<i>P. microphthalmus</i> 10	<i>P. sullivanii</i> n. sp. 10	F df = 27	p
EOD duration (μ s)	436 \pm 142	340	487 \pm 142	216 \pm 29	15.75	**
FFT max (Hz)	4995 \pm 522	6152	4092 \pm 942	9597 \pm 1437	54.14	**
P1 duration (μ s)	152 \pm 15	140	199 \pm 39	91 \pm 7	33.1	**
P2 duration (μ s)	74 \pm 11	60	90 \pm 22	38 \pm 9	18.96	**
P3 duration (μ s)	209 \pm 61	140	198 \pm 116	87 \pm 27	5.07	*
P1 amplitude	0.257 \pm 0.023	0.304	0.260 \pm 0.041	0.237 \pm 0.30	1.75	N.S.
P2 amplitude	-0.742 \pm 0.023	-0.695	-0.739 \pm 0.41	-0.762 \pm 0.030	1.75	N.S.
P3 amplitude	0.051 \pm 0.026	0.045	0.021 \pm 0.006	0.128 \pm 0.036	30.3	**

identified as *P. simus* by various authors, actually belong to different species of *Petrocephalus*. These are morphologically similar to, but clearly distinct from *P. simus*. We believe *P. simus* has an even more restricted geographical distribution, probably limited to the Lower Guinean province. The identification of specimens outside this area (especially in the Congo basin) appears incorrect, for the following two reasons.

First, many authors point to the existence of a black spot near the base of the dorsal fin as a character for *P. simus*, even basing their identification on this spot (Boulenger 1898). However, Bigorne & Paugy (1991) clearly demonstrated that the specimens studied by Boulenger belong to a complex of species, not a single species. The syntypes of *P. simus* lack the black spot, as originally mentioned by Sauvage (1879). In our study, we have never observed any black spot on the specimens from Gabon.

Second, the systematics of *Petrocephalus* is known to be problematic (Bigorne & Paugy 1991; Kramer & Van der Bank 2000). The distinction between species is often based upon slight differences in combinations of morphological characters. *Petrocephalus simus* has no particular or remarkable features, and it has never undergone any systematic revision since its description based on just two specimens from the Ogooué in the 19th century (Sauvage 1879). Since many specimens are without obvious diagnostic characteristics,

they have been attributed to this species even though they were collected elsewhere in Africa, in particular the Congo basin. We have studied specimens from the Sanaga, Nyong and Congo basins, which have been identified as *P. simus*. None of these specimens shows the same combination of characters found in the type series. We conclude that they probably belong to different species (unpublished observations). Moreover, during a recent field trip in the Congo basin, none of the ten species of *Petrocephalus* that one of us (SL) collected corresponds to types of *P. simus*.

A detailed morpho-anatomical study of the electrical catfishes of the family Malapteruridae (Norris 2002) showed that a species with a widespread natural distribution (*Malapterurus electricus*) could actually be a complex of species, each with a restricted distribution. Similar to the results of that study, we suggest that *P. simus* should be considered as endemic to the Lower Guinea ichthyofaunal province (Gabon, Equatorial Guinea, Cameroon and Congo-Brazzaville).

REMARKS ON EODs

The adult electric organs of this species, as in all known *Petrocephalus* species, are composed of plate-like cells called electrocytes with non-penetrating stalks innervated on their posterior faces. This type of electrocyte morphology has been referred to as Type NPp (Alves-Gomes &



FIG. 6. — Photos of live specimens of *Petrocephalus*; **A**, *P. simus* Sauvage, 1879 (from the Ivindo River, near Loa Loa, CU75445, 56 mm SL); **B**, *P. sullivanii* n. sp. (from the Ogooué River, near La Lopé, CU83120, 109 mm SL); **C**, *P. microphthalmus* Pellegrin, 1908 (Ogooué River, near Franceville, CU80479, 64 mm SL). Photographs by Carl D. Hopkins.

Hopkins 1997; Lavoué *et al.* 2000, 2003; Sullivan *et al.* 2000). As in other mormyrids with Type NPp electrocytes, the EODs of *Petrocephalus* are predominantly biphasic in waveform (Bennett 1970). The first phase is thought to result from the synchronous discharge of stalks and posterior faces of the electrocytes; the second phase is thought to result from the discharge of the anterior faces. As the stalk and posterior membranes are depolarized, inward currents are directed anteriorly inside the fish. The return path through the water produces the head-positive first phase to the whole animal EOD. Depolarization and action potentials in the anterior faces of these electrocytes direct current posteriorly within the electric organ to generate a head-negative second phase in the whole animal EOD. The anterior faces are initially depolarized by the passive spread of current from the activity in the posterior faces and stalks. The third phase (P3) of the EOD, which is prominent in *P. sullivanii* n. sp., probably occurs whenever spikes in the posterior faces and stalks persist longer than the spikes in the anterior faces. Similar three-phase EODs have been recorded from *Petrocephalus catostoma* (Günther, 1866) from the Zambezi River (Kramer & Van der Bank 2000). Short, three-phase EODs also occur in *Pollimyrus adspersus* (Günther, 1866) (Westby & Kirschbaum 1978; Hopkins 1980, 1981; Crawford 1991, 1992), and in other mormyrids with very short duration EODs (i.e. less than 300 μ s).

Westby (1984) previously modeled the triphasic EOD of *P. adspersus* by adding a wide positive Gaussian waveform to a delayed narrow negative Gaussian waveform, and was able to simulate natural variations in EODs by slight phase-shifts in the timing of the two waveforms. He speculated that the third phase of these short EODs may be larger or smaller depending upon the relative timing of the short and long parts of the waveform. We believe that a similar mechanism may apply here since there is no obvious physiological basis for a third phase to the waveform other than a longer lasting first phase that persists even after the second, head-negative phase of the EOD produced by firing the anterior faces of the electro-

cytes. We note that the magnitude of peak P3 is inversely correlated with the overall EOD duration when we consider EODs of all four species together (data not shown). Conversely, the magnitude of P3 is directly correlated with the FFT max as illustrated by the regression line in Figure 3 ($r^2 = 0.67$, $p < 0.001$). Thus, the third phase of the EOD is most likely a residual from discharge of the posterior faces and stalks that persists longer than the spike in the anterior faces. The differences in EODs among closely-related species we report here for four species of *Petrocephalus* are smaller in magnitude than the differences reported for various other species of mormyrids, including *Brienomyrus* (Hopkins 1980, 1981; Bass 1986; Sullivan *et al.* 2002; Arnegard & Hopkins 2003), *Campylomormyrus* (Hopkins 1999), *Marcusenius* (Kramer 1997), and *Hippopotamyrus* (Scheffel & Kramer 2000), for which EODs can vary in duration by more than an order of magnitude. Although the variation between *Petrocephalus* EODs is small compared to these other genera, our data for the Gabon *Petrocephalus* suggest an emergence of slight differences between species, especially in the overall duration of the EOD waveform. These differences are consistent, and our study shows that they may be useful for taxonomic purposes.

PRELIMINARY CONSIDERATIONS

ON THE ICHTHYOGEOGRAPHY OF GABON

Gabon is situated in Central Africa and has a complex hydrographical system, dominated by the Ogooué basin (Fig. 7). The drainage area of the Ogooué basin is 205000 km², making it the sixth largest of Africa and its average discharge rate is 4758 m³/sec, making it the third most important in Africa (Vanden Bossche & Bernacsek 1990; Reid 1996). The Ogooué River originates in the Congolese front of the Batéké Plateau, flows across Gabon forming an 820 km-long arc of a circle, and empties into the Atlantic Ocean at Port-Gentil. Its main tributaries are the Ngounié and the Ivindo. Beside the Ogooué, smaller rivers drain the rest of the country. The Ntem River basin, which forms the northern border of Gabon

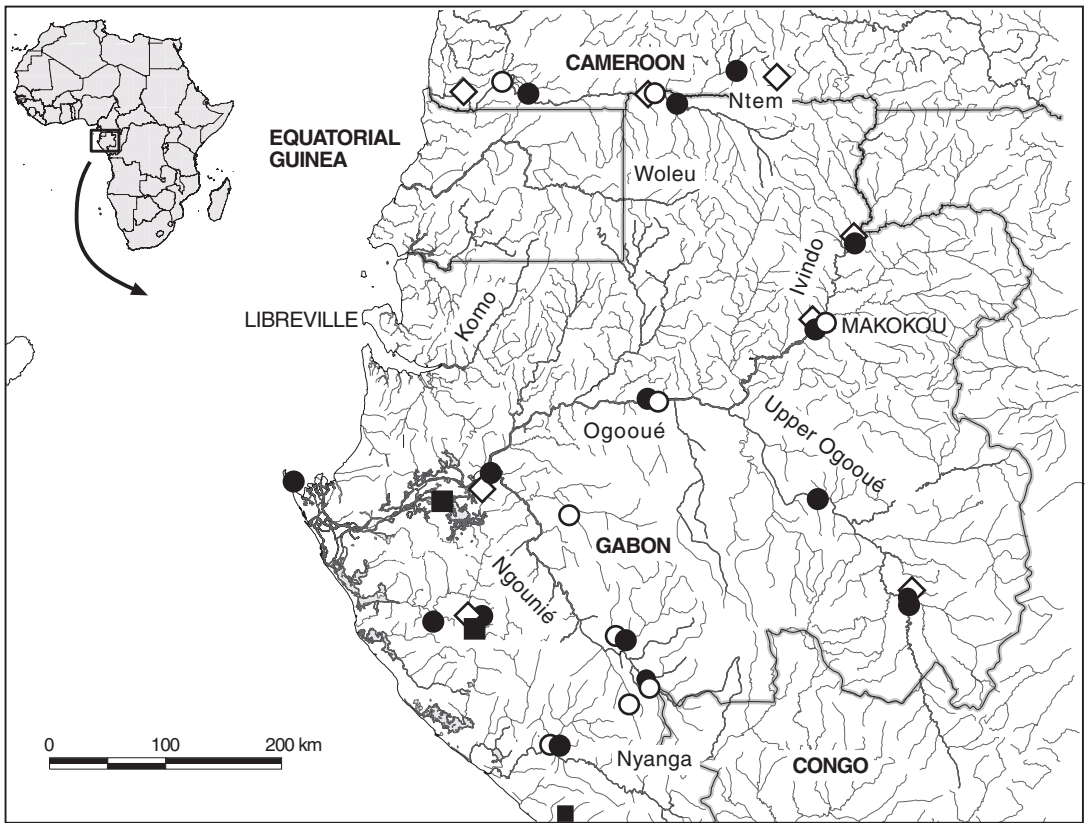


Fig. 7. — Geographical distribution in Gabon of *Petrocephalus simus* Sauvage, 1879 (●), *P. balayi* Sauvage, 1883 (■), *P. microphthalmus* Pellegrin, 1908 (◆) and *P. sullivanii* n. sp. (○).

with Cameroon, drains the extreme north of the country. To its south, the upper basin of the Woleu River drains the rest of this northern province. Finally, from north to south, numerous small rivers drain the coastal forests of the Atlantic seaboard.

On a continental scale, Gabon belongs to the ichthyogeographical province of Lower-Guinea, which contains all of the western hydrographical systems between the Cross basin in the north and the Congolese (previously named Zairian) basin in the south (Roberts 1975). This province is characterised by both a high diversity (more than 300 species reported) and a high level of endemism (Teugels & Guégan 1994). Until recently, data on the systematics and distribution of the freshwater fishes were insufficient to define

ichthyogeographical sub-provinces, to propose historical relationships amongst them and to discuss the process that lead to the biological diversity observed. Thys van den Audenaerde (1966) first proposed the splitting of the Lower-Guinea province into seven sub-provinces based on the distribution of *Tilapia* s.l. (Cichlidae). Four of them occur in Gabon: 1) the brackish zone (this region is not relevant to our discussion because of the intolerance to salt of the Mormyridae); 2) the Upper Ogooué (from its source to Lambaréné); 3) the coastal region, including the Lower Ogooué; and 4) the region including the Ntem, Woleu and Ivindo basins. Except for a few local considerations (Géry 1965; Teugels & Guégan 1994; Kamdem Toham 1998), no other sub-provinces were proposed.

During recent field work in Gabon, we have made collections from all of the major drainages and these preliminary results are based on the study of these collections. The distribution and endemism pattern of the four recognized species of *Petrocephalus* and 11 other species of Mormyridae known in Gabon (excluding species belonging to the “Gabon-clade *Brienomyrus*” [Sullivan *et al.* 2002], because taxonomic revision is in progress [C. D. Hopkins, J. P. Sullivan and G. Teugels pers. comm.]) allow us to define three ichthyogeographical sub-provinces.

The first sub-province contains the Ivindo and Ntem basins in north/north-east Gabon. These two basins share several endemic species and two genera (e.g., *Boulengeromyrus knoepffleri* Taverne & Géry, 1968, *Ivindomyrus opdenboschi* Taverne & Géry, 1975, *Marcusenius ntemensis* (Pellegrin, 1927)). Moreover, populations of *Petrocephalus simus* from the Ntem and Ivindo basins are morphologically closer than they are to populations outside. This is also true for populations of *Petrocephalus sullivanii* n. sp. The affinities between the Ivindo and Ntem basins have been already mentioned (Thys van den Audenaerde 1966; Kamdem Toham 1998). In the past, the Ivindo River was part of the upper course of the Ntem River before the Ogooué basin captured it. Nowadays, the Ivindo discharges into the Ogooué, after a series of waterfalls, some of which are relatively high. These waterfalls constitute a physical barrier preventing fish dispersal. Additionally, ecological factors could play a role. The Ivindo has black water (similar to that of the Ntem), whereas the Ogooué has green water with different physical and chemical characteristics.

The second region contains the Ogooué basin from its source to the vicinity of Lambaréné,

excluding the Ivindo River. Despite the multitude of rapids that occur along its course, mormyrid diversity is homogeneous. Mormyrid species that characterise this region are *Stomatorhinus walkeri* (Günther, 1867), *Mormyrops* cf. *nigricans* Boulenger, 1899 and *Brienomyrus* cf. *brachyistius* (Gill, 1863) “form A”. We did not observe any significant morphological difference amongst populations of *P. simus*, *P. microphthalmus* and *P. sullivanii* n. sp. from different localities.

The third region is the coastal freshwater system, constituting of the lower course of the Ogooué and all of the small coastal rivers from the North to the South. In comparison to the first two regions, there are less species of Mormyridae represented. At least three species are characteristic for this region, *Petrocephalus balayi*, *Brienomyrus* cf. *brachyistius* “form B” and *Isichthys henryi* Gill, 1863 (although the latter species also has some unexpected populations occurring in the Ivindo system). Despite recent investigation of the Nyanga basin, the diversity of this basin remains still poorly known and more study is necessary to assign it to a particular sub-province.

These preliminary results indicate that common factors and physical barriers shaped ichthyogeographical patterns in this region. However, because overall similarity is not necessarily synonymous with close relationships, we are not able to further discuss the evolution and dispersal of the freshwater fishes amongst these defined regions. Fine-scale analyses of wide-ranging mormyrid species such as *Mormyrops zanclirostris*, *Marcusenius moorii*, *P. microphthalmus*, *P. simus* or *P. sullivanii* n. sp. could provide more data on the evolution and the dispersal of freshwater fishes of this region.

KEY TO THE SPECIES OF *PETROCEPHALUS* FROM GABON

1. Distinct sub-dorsal black spot present, wide mouth; more than 25 teeth in the lower jaw; width between 2.7 and 3.9 times in head length *P. balayi*
- Sub-dorsal black spot absent; fewer than 25 teeth in the lower jaw; narrow mouth, width at least 3.6 times in head length..... 2

2. 15 to 18 branched rays in the dorsal fin; 8 to 10 scales between the origin of the anal fin and the lateral line; small eye, diameter at least 4.1 times in head length *P. microphthalmus*
- More than 18 branched rays on the dorsal fin, rarely 18; more than 10 scales between the origin of the anal fin and the lateral line, diameter of the eye at most 4.1 times in head length 3
3. Mouth posteriorly-positioned; opening below the posterior half of the eye; distance between the anterior extremity of the snout and the corner of the mouth at least 3.8 times (average 4.7) in head length; 14 to 20 (average 17) scale rows between the anterior base of the anal fin and the lateral line; EOD possesses a third positive phase..... *P. sullivanii* n. sp.
- Mouth in sub-terminal position, slightly lower-positioned; opening under the anterior half of the eye; distance between the anterior extremity of the snout and the corner of the mouth at most 4.4 (average 3.2) times in head length, 10 to 16 (average 14) scales rows between the anterior base of the anal fin and the lateral line; EOD lacks a third positive phase *P. simus*

CLÉ DE DÉTERMINATION DES ESPÈCES DE *PETROCEPHALUS* DU GABON

1. Présence d'une tache arrondie, noire et bien distincte sur chacun des flancs ; plus de 25 dents sur la mâchoire inférieure ; bouche de grande taille dont la largeur est comprise moins de 3,9 fois dans la longueur de la tête *P. balayi*
- Absence de tache noire sous les premiers rayons de la nageoire dorsale ; moins de 25 dents sur la mâchoire inférieure ; bouche étroite dont la largeur est comprise plus de 3,6 fois dans la longueur de la tête 2
2. De 15 à 18 rayons branchus au maximum à la nageoire dorsale ; de 8 à 10 écailles au maximum entre la base antérieure de la nageoire anale et la ligne latérale ; œil de petite taille, dont le diamètre est compris plus de 4,1 fois dans la longueur de la tête *P. microphthalmus*
- Plus de 18 rayons branchus à la nageoire dorsale, rarement 18 ; plus de 10 écailles entre la base antérieure de la nageoire anale et la ligne latérale ; diamètre de l'œil compris moins de 4,1 fois dans la longueur de la tête 3
3. Bouche nettement infère, s'ouvrant à la verticale de la seconde moitié de l'œil ; distance entre l'extrémité antérieure du museau et la commissure de la bouche comprise au minimum 3,8 fois (en moyenne 4,7) dans la longueur de la tête ; 14 à 20 écailles entre la base antérieure de la nageoire anale et la ligne latérale (en moyenne 17,5) ; impulsions électriques organiques triphasiques, avec une troisième phase positive *P. sullivanii* n. sp.
- Bouche sub-terminale, légèrement ventrale, s'ouvrant sous la première moitié de l'œil ; distance entre l'extrémité antérieure du museau et la commissure de la bouche comprise au maximum 4,4 fois (en moyenne 3,2) dans la longueur de la tête ; 10 à 16 écailles entre la base antérieure de la nageoire anale et la ligne latérale (en moyenne 14) ; impulsions électriques organiques biphasiques *P. simus*

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